Mid-Frequency Sonar Interactions with Beaked Whales

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LONG-TERM GOALS

The top-level goal of this project is to build an interactive online modeling and visualization system, called the Virtual Beaked Whale, to enable users to predict mid-frequency sonar-induced acoustic fields inside beaked whales and other marine mammals. Another high-level goal is to acquire new high-resolution morphometric and physical-property data on beaked whales for use in the model. It is hoped that the availability of such a system together with high-quality data will give researchers insight into the nature of sonar interactions with beaked whales, ultimately to introduce objectivity into a public discussion that has been hampered by lack of a scientific approach. It is hoped further that the tool will prove useful in evaluating alternate sonar transmit signals that retain the required information content but with substantially reduced physical effects in beaked whales.

OBJECTIVES

To achieve the long-term goals, a number of scientific and technological objectives have been identified. These include the following: To develop and apply computer codes, based on the finite-element method for acoustic interactions with structures, to beaked whales and mid-sonar frequencies in the range 1-10 kHz. To collect high-resolution morphometric data on beaked whales from *post-mortem* materials. To construct finite-element models of the anatomy, and to assign physical properties of tissues. To verify the finite-element code. To incorporate the finite-element code and

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morphometric and physical-property data in an online modeling and visualization system called the Virtual Beaked Whale.

APPROACH AND WORK PLAN

The approach and work plan are organized around an integrated set of six tasks, which are briefly elaborated.

Task 1. Development of a finite-element method to model acoustic interactions: The equations that govern acoustic interactions with structures are respectively acoustic and elastodynamic. These will be solved for the case where the structure is a beaked whale as represented by its morphometry (Task 2), illustrated for a common dolphin in Figure 1, and where each part is assigned its respective set of physical properties (Task 3). This work is being led by Co-PI Feijoo, with support by the PI. It is expected that the method will be sufficiently developed to model acoustic interactions with heterogeneous fluid-like bodies by the end of the upcoming year.

Task 2. Morphometry and meshing the three-dimensional anatomy: These data will be acquired from computerized tomography (CT) scans, as in Figure 1a. The image data on cetacean specimens will be expressed in Digital Imaging and Communications in Medicine (DICOM) format. Amira visualization software will be used to identify and triangulate the surface corresponding to different tissues, as in Figure 1b. A finite-element mesh will be constructed from these data, as in Figure 1c-e. It is expected that some CT data will be provided by the WHOI Computerized Scanning and Imaging Facility, led by WHOI Senior Scientist D. Ketten. Other CT data may be provided by collaborators, including S. Ridgway of the U.S. Navy Marine Mammal Program and D. Houser of Biomimetica, and C. Potter and J. Mead of the Smithsonian Institution. It is expected that morphometric data on six marine mammals will be available by the end of the upcoming year. Co-PI Reidenberg will be responsible for interpreting the anatomical data. Co-PI Feijoo will construct finite-element meshes from the anatomical data.

Task 3. Physical properties of tissues: The best available data, including both published and new data, will be used to represent the acoustically important properties of mass density, elastic constants, and absorption coefficients for each identified internal organ or other body part. This task will be led by the PI, with potential contributions of new *in situ* data from P. Rogers at the Georgia Institute of Technology. Work on populating a database of properties will be started in the upcoming year.

Task 4. Measuring interactions of acoustic fields with cetacean carcasses: In order to test the finite-element code (Task 1), measurements will be performed of the internal fields in instrumented carcasses of marine mammals at the Naval Surface Warfare Center – Carderock Division. Carcasses will be prepared by surgically implanting acoustic sensors; CT-scanned to determine the morphometry and location of sensors; then acoustically measured at the NSWC facility. D. Ketten will perform the surgery and CT-scanning. Co-PI Rye will lead the measurement work at Carderock, supported by J. Clark, who is developing a novel electromagnetic source transducer. The Carderock facility is essentially ready to begin measurements, but development of the electromagnetic source transducer is ongoing. It is expected that two carcasses of marine mammals will be measured during the upcoming year.

Task 5. Testing the FEM model: Rigorous testing will be performed by comparison with immersed simple objects for which analytical solutions are known. These solutions are being identified or

extended, and numerically realized for acoustically absorptive fluid spheres in a lossy immersion fluid. The PI is leading this task, with support by Co-PI Feijoo. Comparisons with several analytical and some other known numerical solutions are expected to be completed during the upcoming year.

Task 6. Virtual Beaked Whale: This interactive online modeling and visualization system is the principal deliverable of the project. It incorporates a database with sets of whole-body morphometric data (Task 2) from beaked whales and other species, illustrated in Figure 1, as well as the respective physical properties of tissues (Task 3). However, it also allows the user to enter other morphometric and physical-property data directly. The user will be able to specify an essentially arbitrary mid-frequency sonar signal. The output will consist of computed solutions for the internal field (Task 1) at user-specified locations. The user interface is being specified by Co-PI Hastings. Co-PI Feijoo is designing the system and directing programmers in implementation sub-tasks. Co-PI Hastings will also perform testing and quality assurance. The PI will coordinate the various sub-tasks in addition to participating in the work. It is expected that user needs will be defined and test cases will be developed in the upcoming year.

WORK COMPLETED

Funding was received in August 2007, and while progress has been made on a number of tasks, no major tasks have been completed.

RESULTS

Funding was received in August 2007 and some results have already been achieved, but these are considered partial and premature for description here.

IMPACT AND APPLICATIONS

National Security

At present, Navy operations at sea can be affected by the presence of marine mammals, hindering the use of sonar. The Virtual Beaked Whale will enable researchers to gauge the physical effects of particular sonar transmit signals on interactions with marine mammals. If the internal pressure or particle displacement at particular locations is found to be harmful, modifications to the sonar transmit signal waveform can be investigated quantitatively. This may lead to the discovery or identification of alternate sonar transmit signals, enabling sonar operations to be continued in the presence of marine mammals, but with use of safe transmit signals that still provide the required information content for Navy purposes.

Economic Development

Sonars, including echo sounders, are manufactured in the U.S. and in a number of other countries. Use of the Virtual Beaked Whale will enable alternate transmit signal waveforms to be investigated with respect to their potential effects on marine mammals as well as other aquatic animals. By opening a discussion on alternate signals, it is expected that sonar businesses will discover that there are advantages in terms of information content that go well beyond those of safe operation in the presence of organisms.

Quality of Life

Coastal resources are widely appreciated to be precious, witness, for example, the precarious state of the right whale, which summers chiefly in the Gulf of Maine. Similarly, ecosystem health is recognized to be important to the quality of everyday life, as expressed, for example, in consumer concerns about the effects of mercury and PCBs on fish as a food product. An important tool in the assessment and management of fish and other aquatic biological resources, as well as ecosystems, is acoustics. Safe operation of sonars and other active acoustic devices used in this work is essential. The Virtual Beaked Whale is expected to contribute significantly to the process of ensuring safe acoustic operations.

Science Education and Communication

The new tool, the Virtual Beaked Whale, will be interactive. It is expected that the cumulative experience of users will contribute to new knowledge about acoustic interactions with marine mammals and other forms of aquatic life, also increasing public confidence in the value of data-based technology. The tool may be used by educators to promote education in fields as diverse as aquatic science, ecosystem assessment, resource conservation, and sonar engineering, also stimulating the kind of discussions that advance science.

TRANSITIONS

Funding was received in August 2007, therefore products have not yet been developed, precluding incorporation into more developmental or operational programs or plans.

RELATED PROJECTS

This project may benefit directly from a number of other projects. Three are cited. (1) Professor P. Rogers at Georgia Institute of Technology is currently investigating methods for determining elastic properties of cetacean head tissues *in vivo* under a grant from ONR. The quality of these will be unprecedented and of high value to the NOPP project. (2) Dr. S. Ridgway of the U.S. Navy Marine Mammal Program and Dr. D. Houser of Biomimetica have offered to provide morphometric data on living dolphins. These are unique and of high value to the NOPP project. (3) The Center for Ocean Sciences Education Excellence - New England (COSEE-NE) will be assisting the NOPP project in tailoring the interactive online tools under development to specific audiences. It will also be assisting in the dissemination of the results of the research and new educational tools.

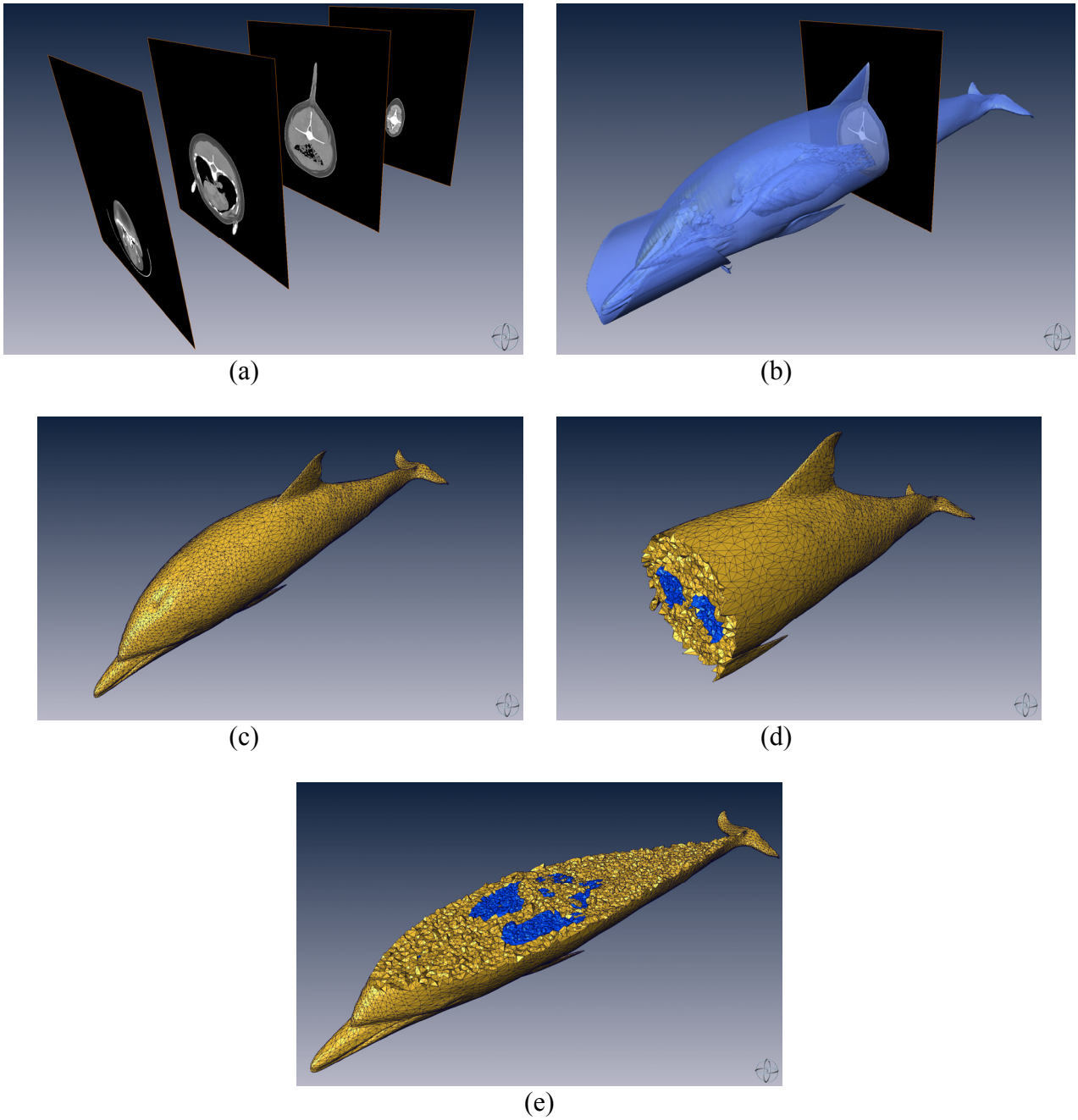

Figure 1. Visualizing the morphometry of a marine mammal, illustrated for a 170-cm-long common dolphin. (a) CT scans. (b) Visualization of the whole body and air cavities. (c) Surface triangulation. (d,e) Volumetric mesh revealed in cross sections.